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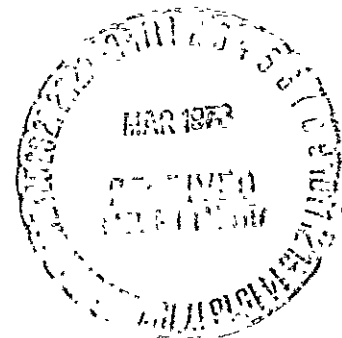
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March 1976

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Goddard Space Flight Center



(E78-10074) USE OF LANDSAT-1 DATA FOR THE
DETECTION AND MAPPING OF SALINE SEEPS IN
MONTANA (Pennsylvania State Univ.) 87 p HC
A05/MF A01 CSCI 00

USE OF LANDSAT-1 DATA FOR THE DETECTION AND MAPPING OF
SALINE SEEPS IN MONTANA

G. A. May and G. W. Petersen

for

National Aeronautics and Space Administration
Goddard Space Flight Center

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The Pennsylvania State University
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Space Science and Engineering Laboratory
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**ORIGINAL CONTAINS
COLOR ILLUSTRATIONS**

ORSER-SSEL Technical Report 4-76
March 1976

Acknowledgments

Financial support for this study was provided by the National Aeronautics and Space Administration, Goddard Space Flight Center (Contract No. NAS5-2304).

Appreciation is extended to Jack Rodgers, Montana State Soil Scientist, for selecting the study site and providing aerial photographs of the area.

Special thanks to Clair Clark, Fergus County Soil Scientist, for his sincere help in collecting ground truth information for this project.

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I. INTRODUCTION

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A. Objective

Saline seeps are a serious threat to the conservation and economy of Montana. Although they destroy an estimated 3,200 to 10,000 additional hectares of productive Montana land each year, data are unavailable to locate, to map their extent, or to determine the growth rate of saline seeps (1). This study was conducted to determine the feasibility of using Landsat-1 to detect and map saline seeps in Montana.

B. Definition and Description of Saline Seeps

Saline seeps are recently developed wet salty areas in non-irrigated soils that are wet some or all of the time, often with white salt crusts, and where crop or grass production is reduced or eliminated (1, 10). Saline seeps are caused by the crop fallow system of farming superimposed on the geologic, hydrologic, and soil conditions of Montana and the Northern Great Plains.

Figure 1 depicts the formation of a saline seep. The surface material is glacial till which has a maximum depth of 21 meters (3). These deposits are underlain by a thick marine shale formation that is impermeable to water. Both the shale and glacial till contain an abundant supply of natural soluble salts. Excess water percolates through the soil and dissolves salts out of the soil and substratum. When the salty water reaches

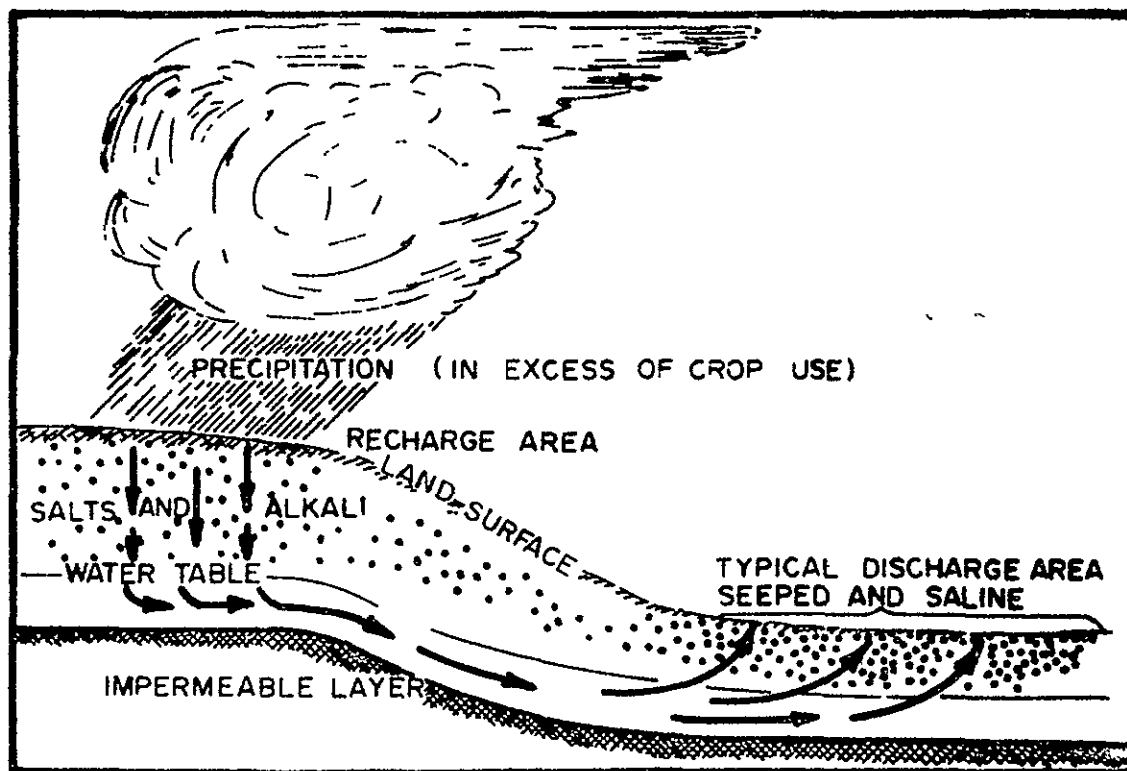


Figure 1. Formation of a saline seep.

The soil and substratum consists of glacial till which overlies impermeable shale bedrock. Precipitation infiltrates this soil (recharge area) and percolates through the glacial till dissolving out salts. A perched water table develops on the impermeable shale causing downslope water flow. When this salty water reaches a slope break, it emerges at the surface by capillary rise to form a saline seep (discharge area).

the impermeable shale, a perched water table is formed. This excess water moves downslope and accumulates in pockets. The water then moves to the surface by capillary rise to form a saline seep (discharge area) and then evaporates leaving the dissolved salts behind (Figure 1). These salts frequently accumulate and form white salt crusts of varying thickness. The recharge area is upslope from the seep where the percolating water originates. Saline seeps are a result of local, not regional, flow systems; therefore, the recharge area is in close proximity to the discharge area.

Seeps may develop on sidehills, near hilltops, at the base of hills, or on lowlands. Seeps usually occur where there is a sudden change in the slope of the land, but they do not have to be associated with a low point in the topography (6).

Present crop-fallow farming or summer fallowing practices are the principal cause of saline seep problems in Montana. The average annual precipitation in Montana is 30 to 38 centimeters which is insufficient moisture to grow an economic wheat crop. To increase soil water, the farmers leave half of the tillable land bare for at least 14 months out of each 24 months where winter wheat is the crop and 20 months out of 24 months where oats, spring wheat, or barley are the crops (4). The precipitation that falls during the periods of fallow ground is free to percolate through the soil and flow downslope to form a saline seep.

Figure 2 is an aerial photograph which shows the field patterns of crop-fallow farming. The longest strips on this photograph are 800 meters. The golden colored strips contain winter wheat that is ready for harvest. The fallow strips are dark in color and contain only bare soils which are void of vegetation due to periodic harrowing. Next year, the fallow strips will be planted in wheat and the current wheat fields will be left fallow to store precipitation that falls throughout the year. In reality, a large percentage of the stored water is lost to vertical and horizontal flow resulting in the formation of a saline seep. The white area in the bottom right-hand portion of Figure 2 is a large saline seep. Several smaller seeps are also evident in the photograph.

Summer fallow acreage in Montana has increased steadily over the past decades: 1.1 million hectares in 1930, 1.7 million hectares in 1950, and 2.5 million hectares in 1964 (7). This has resulted in a corresponding increase in saline seep development. Other factors have also contributed to the saline seep problem. Soil and water conservation practices such as strip and contour farming, stubble mulching, and snow barriers have augmented water infiltration and percolation.

Saline seeps increase in size at an estimated average rate of 10 percent annually with some increasing

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Figure 2. An aerial photograph showing the field patterns of crop-fallow farming with a large saline seep in the lower right.

The gold strips contain wheat and the dark strips are bare soil. The length of the longest strip is 800 meters. Saline seeps are discerned by the white crustal formations. A large seep is located in the bottom right of this photograph.

by as much as 160 percent annually (5). The amount of precipitation, evaporation, transpiration, and size of the recharge area regulates, to a large extent, the growth rate of a saline seep.

C. Extent and Effects of Saline Seeps

The Soil Conservation Service estimated that Montana had 33,000 hectares of saline seeps in 1971 and 61,000 hectares in 1973, an increase of 51 percent (8). An estimated 590,000 square kilometers of the Northern Great Plains have potential for saline seep development based on geologic and soil conditions (Figure 3). Over 44,000 square kilometers of this total are found in Montana.

An example of a saline seep that has developed within a wheat field is shown in Figure 4. The seep is less than 1 hectare and did not exist 3 years prior to the date of this photograph. Plants cannot grow on this seep because of the high salt concentration, however, some salt-tolerant weeds are growing on the periphery of the seep. This land is not only lost to crop production, but it also costs the farmer time and money to work around the seep. In most cases, farm equipment is unable to operate in the saline seeps due to their high moisture content

Saline seeps are also responsible for the deterioration of shallow groundwater aquifers and increasing saline pollution of Montana's streams and reservoirs.

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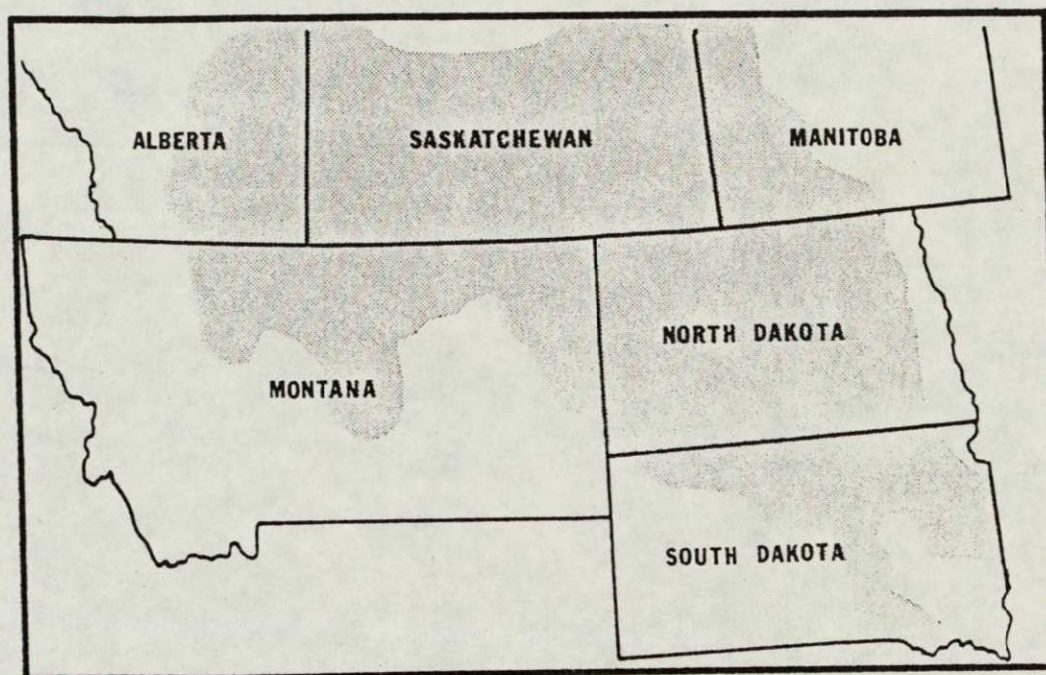


Figure 3. Area of potential saline seep development in the Northern Great Plains.

The darkened area represents 590,000 square kilometers in the Northern Great Plains region that has potential for saline seep development. Over 44,000 square kilometers of this total are in Montana.



Figure 4. Saline seep development in a wheat field.

This seep is less than 1 hectare in size and did not exist 3 years prior to the date of this photograph. Plants cannot grow on the seep because of the high salt concentration. Some salt-tolerant weeds are growing on the periphery of the seep.

is encountered which is difficult to control. Also, the root system of small grains extend to a depth of only 1 to 2 meters and will not deplete the stored moisture at greater depths.

Alfalfa and tall wheat grass are better plants for drying out the soil. Both plants are somewhat salt-tolerant and have deep root systems. Alfalfa can use soil moisture to a depth of 7.5 meters once it gets established (1). Planting and managing these plants in and adjacent to existing or potential seep discharge areas will deplete stored moisture and help contain further seep development. It is, therefore, very important to detect and map saline seeps so that known technology can be applied to these areas to contain and prevent their growth.

II. METHODS AND MATERIALS

A. Selection of Study Site

A study site was selected in Fergus County, Montana in cooperation with Jack Rodgers, Montana State Soil Scientist. The area includes the town of Coffee Creek which is located approximately 100 kilometers southeast of Great Falls and 55 kilometers northwest of Lewistown (Figure 5). Coffee Creek is located on Route 235 and is easily accessed by taking Route 191 north from Lewistown. The Soil Conservation Service described this area as having severe saline seep problems.

B. Data Analyzed

The following four Landsat-1 scenes were selected for analysis: August 26, 1972, May 22, 1973, June 22, 1974, and September 2, 1974 (scene numbers 1034-17455, 1303-17405, 1699-17330, and 1771-17302, respectively). These were the only cloud-free images available from spring and fall Landsat-1 data. The multispectral scanner data for these dates were obtained and analyzed on an IBM 370 computer, Model 168, using the Penn State/ORSER system. A detailed discussion of the procedure used in analyzing the Landsat-1 data is given in Appendix A. Signatures were developed and classification maps produced using the supervised and unsupervised classification routines (2, 9). All

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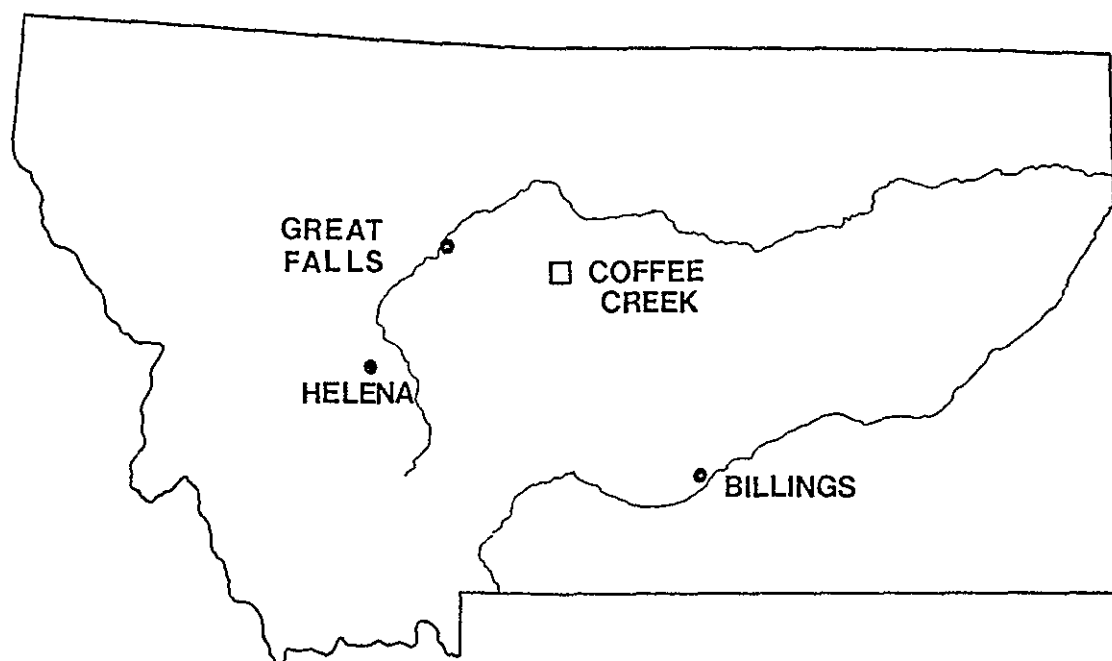


Figure 5. Location of the Coffee Creek study site.

Coffee Creek is located in Fergus County, Montana and is approximately 100 kilometers southeast of Great Falls and 55 kilometers northwest of Lewistown. Coffee Creek is located on Route 235 and is easily accessed by taking Route 191 north from Lewistown. The Missouri and Yellowstone River systems are delineated in their eastward progression across Montana.

classification maps were geometrically corrected to a scale of 1:24,000.

C. Ground Truth

The initial ground truth was 1:24,000 black and white aerial photographs taken on July 23, 1972. Midway through the project, a need for more detailed ground truth necessitated an inspection of the Coffee Creek area.

August 11 and 12, 1975 were spent in Montana obtaining information on saline seeps and collecting field data at the study site. August 11 was spent on the Highwood Bench, located in Chouteau County, which is a saline seep area being studied by several research groups. Mr. Clair Clark, Fergus County Soil Scientist, and Dr. Paul L. Brown, a saline-seep investigator for the Agricultural Research Center, USDA, gave a field review on saline seeps and related problems occurring within the bench.

With the aid of Clair Clark, detailed field data were collected at the Coffee Creek study site on August 12. Information concerning current field patterns, crops, and the extent and location of saline seeps were recorded on the 1:24,000 aerial photographs and acetate overlays and used as ground truth information.

D. Interaction With Potential Users and Investigators

Several people were contacted within Montana to help coordinate this research effort. During this study, saline seep investigators and potential users from the Northern Great Plains region contacted ORSER personnel requesting information concerning the project. The names and addresses of these people and organizations along with some of their correspondence are given in Appendix B.

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III. RESULTS AND DISCUSSION

A. Initial Results

Signature banks were developed and classification maps produced for the study site from Landsat-1 multi-spectral scanner data collected on each of the four dates. These initial maps gave variable results. Some areas delineated as seeps from the spring data were correlated with saline seeps shown on the aerial photographs, but in other cases large areas classified as seeps did not appear on the photograph. The fall classification results contained only a few saline seeps that could be associated with the ground truth information. This inconsistency between the two spring and two fall classification maps and the aerial photographs necessitated the trip to the study site to collect field data.

B. Saline Seep Characteristics

The ground truth trip was an invaluable asset to this research project. A great deal of knowledge was acquired, such as the optimum times to detect seep discharge areas, the soil conditions of seep areas, and vegetative types associated with saline seeps.

Spring and early fall are the best times to detect saline seeps. In the spring soil moisture is at a maximum. The excess water brings the greatest amounts of salts to the surface (discharge area) than at any

other time throughout the year. These salts contain a large amount of sodium which disperses the soils in the discharge area. Accumulations of the salts result in crustal formations as shown in Figure 6. These salt crusts are easily detected because of their high reflectance and can be used to locate saline seeps

Specific native plants, considered as weeds by the wheat farmer, are found growing on and around saline seeps. Because of their salt tolerance, these plants are a valuable aid in mapping saline seeps and have been collectively termed saline seep "indicator plants." Two of these plants are shown in Figure 7. The plant species in the upper right corner of the photograph is foxtail barley. It has no economic value but when this weed growth stands over winter, it traps snow which adds excess water to the saline seep. The green plant growth occurring in Figure 7 is kochia. This deep-rooted and vigorous water-using plant is the predominant vegetation growing on most saline seeps. This plant remains green until the first killing frost while the wheat plant turns gold as it matures in early fall. The most salt-tolerant plant growing on saline seeps is inkweed (Figure 6). It is a short, stemmy plant that usually does not occur in dense stands like the kochia and foxtail barley (Figure 16).



Figure 6. Close-up view of crusted salts and an inkweed plant.

Water containing soluble salts emerges on the surface of discharge areas and evaporates leaving the salts behind. The inkweed is the most salt-tolerant plant in Montana. The black lens cap provides a scale.

inkweed - *Distichlis stricta*



Figure 7. Saline seep identifiers.

The salt-tolerant foxtail barley (upper right), kochia (lower left), and white salt crusts are indicative of saline seeped areas. Because of its high reflectance, the salt crust is easily detected using multispectral scanner data.

foxtail barley - *Hordeum jubatum*

kochia - *Kochia scoparia*

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Figure 8. An aerial photograph of the Coffee Creek study site.

The town of Coffee Creek is located below and to the left of A. A saline seep is located to the left of B. Other seeps are found in the areas of A and C. This study site is approximately 65 square kilometers in size. The scale of this photograph is 1 cm = 0.4 km.

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upper left portion of this figure is 800 meters. The triangular field, denoted by letter B, contains tall wheatgrass. The area to the left of this field is a saline seep. A large seep is located at point A and a part of this seep is easily discerned by the white horseshoe-shaped, salt crusted area. Other seeps, within the area of letter C, are transecting and destroying field boundaries. The southwest-northeast trending linear feature situated below point C is a bench ridge.

Data analyses were concentrated on the August 26, 1972 and May 22, 1973 scenes. In all of the following classification maps, the areas marked by letters A, B, and C correspond exactly to the same areas in Figure 8. Figure 9 is a classification map of the study site using the August data. This map covers the same area shown in Figure 8 and the solid black areas on this map correspond, in most cases, to the darkest grey tones on the aerial photograph. The symbol X represents tillable land and the dots are areas of green vegetation. Two of the indicator plants, kochia and inkweed, are still green at this time of the year. It appears that part of the horseshoe-shaped seep (A) is being mapped by the detection of these indicator plants. But the same signatures are mapping the tall wheatgrass field (B) and also the grasses growing on the bench ridge (see Figures 8 and 9).

Figure 9. Classification map of the Coffee Creek study site using the August 26, 1972 data.

The letter X depicts tillable land and the dots (.) represent green vegetation. The dark areas and the areas denoted by A, B, and C correspond to the same areas in Figure 8 (Scale 1 cm = 0.4 km).

Figure 10 is a classification map of the May 22, 1973 data of the same area shown in Figure 8. The dots represent saline seeps which are being mapped by the detection of salt crusts. A portion of the horseshoe-shaped seep (A) is being correctly classified, and salts along the stream channels are also being detected. Several of the saline seeps classified in Figure 10 overlay saline seeps shown in Figure 8, but there is considerable confusion in the mapping results.

Due to these unsatisfactory classification maps, the data from the May and August scenes were merged using the MERGE program (2). To merge the two sets of data, a specific point in the study site was located in both the May and August scenes and identified by its respective scan line and element numbers within the digital output from the multispectral scanner data. This is necessary to insure proper registration of the May and August data during the merging process. The program merges the four-channel May and four-channel August data obtained over exactly the same area on the earth, thus eight channel signatures were developed for this area. Merged data are useful in studying the effects of temporal change and also improve the classification of certain targets.

An analysis was performed on the merged data and the resultant classification map is shown in Figure 11.

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Figure 10. Classification map of the Coffee Creek study site using the May 22, 1973 data.

The dots (.) represent saline seeps which are being mapped by the detection of salt crusts. The areas denoted by A, B, and C correspond to the same areas in Figure 8 (Scale 1 cm = 0.4 km).

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Figure 11. Classification map of the Coffee Creek study site by merging the August 26 and May 22 data.

The theta symbol (θ) represents tall wheatgrass, dots (.) depict saline seeps, and the letter X represents tillable land. The dark areas and the areas denoted by A, B, and C correspond to the same areas in Figure 18. The scale of this computer output is approximately 1:40,000. An acetate overlay of this figure is included in a pocket on the back cover of this report.

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The theta symbol (θ) represents tall wheatgrass and the dots (.) depict saline seeps. The seep to the left of the triangular field (B) was correctly classified. The seeps mapped in the area of letter C are easily correlated to those in the aerial photograph. The large seep (A) and the seeps occurring along the stream channel are also being mapped. The remaining seeps mapped on Figure 11 overlay seeps shown in Figure 8. An acetate overlay of Figure 11 is included in a pocket on the back cover of this report.

A portion of the horseshoe-shaped seep is shown in Figure 12. Large areas of salt crusts are still visible in mid-August. A mixture of foxtail barley and kochia is located in the foreground. Dense stands of these two plants were found covering large areas on the saline seep.

The researchers traversed the area denoted by letter A in Figure 8. The soils of this area were dispersed due to their high sodium contents. Most of the soils had salts on the surface and supported good stands of indicator plants. These factors indicate that this entire area is a saline seep. It is impossible to determine the extent of this seep from the aerial photograph, but it was completely mapped using the merged data (Figure 11). The saline seep located at A is over 60 hectares, excluding areas along the stream channels.

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Figure 12. A portion of the horseshoe-shaped saline seep at Coffee Creek.

A mixture of foxtail barley and kochia is located in the foreground and center of this photograph. In the spring, this would be salt-covered and void of vegetation.

Table 1. Saline seep spectral responses from the merged data for the Coffee Creek study site.

Signature Number	Channels							
	August 26, 1972				May 22, 1973			
	1	2	3	4	1	2	3	4
1	34.50	33.67	40.50	19.67	107.50	118.17	112.50	51.17
2	28.20	25.40	30.00	14.20	88.80	95.40	89.60	40.40
3	27.57	24.57	30.71	15.57	68.14	73.00	75.86	35.71
4	27.65	24.77	32.08	16.96	54.85	56.92	62.50	30.88
5	26.29	22.26	35.60	19.74	38.78	38.18	50.23	26.78
6	24.73	23.19	34.31	20.63	35.25	34.62	46.06	27.31

field conditions. Mr. Clark found that most of the saline seeps delineated on the classification maps were in the field but that several seeps were not mapped by the computer. These were seeps that were less than 2 hectares in size or those that had linear configurations that were less than 200 meters in width. The inability to map these seeps is because of the resolution of the Landsat-1 multispectral scanner. It may be possible to map smaller seeps if the area imaged by the Landsat-1 scanner pixel falls within the confines of these seeps.

Saline seep mapping capability was also decreased because of similar spectral responses from foxtail barley (a saline seep indicator plant) and wheat. This is illustrated in Figure 13 where foxtail barley, located in the right half of this photograph, is very similar in color to the wheat that occurs in the bottom left of Figure 13. The foxtail barley plants are visibly distinguishable from the wheat, but at this time of the growing season it is impossible to differentiate these plants using Landsat-1 data.

The ability to map seeps that sustain foxtail barley can be greatly increased with data collected after the wheat has been harvested. This is a time when differences can be detected between the harvested wheat and foxtail barley as shown in Figure 14. The cut wheat is spectrally different from the growing

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Figure 13. Landscape view showing the spectral similarities between wheat and foxtail barley.

Foxtail barley, located in the right half of this photograph, has similar color to the wheat which occurs in the bottom left. A small area of kochia is located behind the wheat.



Figure 14. A landscape view of a saline seep located in a wheat field.

The saline seep in the center of this photograph is approximately 20 hectares in size. Foxtail barley, growing on the saline seep, is discernable from the harvested wheat field.

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foxtail barley located in the center of this photograph. Landsat-1 data collected during this period should allow for distinct classification between these two plants, thus enabling detection of saline seeps that support stands of foxtail barley.

The classification map of the merged data was reproduced in color using the computer's character printer and colored ribbons (Figure 15). This map had an original scale of 1:24,000 and was geometrically corrected. In Figure 15, the saline seeps are red, tall wheatgrass is green, and the tillable land is grey. The black areas correspond to the darkest tones in Figure 8. Four ribbons (red, blue, green, and black) are available for producing colored output. Each color has six tones, therefore, by including white, a maximum of 25 color levels can be obtained.

D. Signature Extension

The saline seep signatures derived from the merged data were extended outside the Coffee Creek study site to determine if these signatures could be used to map saline seeps in another area. The RAMTEK, an interactive colored monitor system being developed by ORSER personnel, was used in this part of the study. The results of signature extension is shown in Figure 16. Saline seeps are depicted by white, tall wheatgrass is tan, and the bench ridges, drainage channels, and some wheat fields are blue. The majority of the



Figure 15. Computer-colored classification map of the Coffee Creek study site from the merged data.

Red represents saline seeps, tall wheatgrass is green, and grey (+) depicts tillable land. The black areas correspond to the darkest grey tones in Figure 8. (Scale 1 cm = 1 km)

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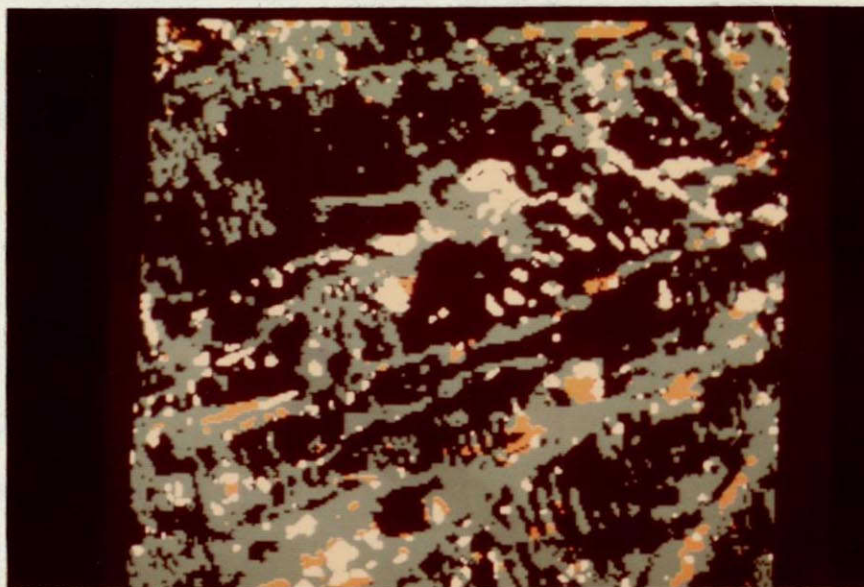


Figure 16. Classification map photographed from the RAMTEK color monitor showing signature extensibility.

This photograph was taken off the RAMTEK color monitor. Saline seeps are depicted by white, tall wheatgrass is tan, and the bench ridges, drainage channels, and some wheat fields are blue. Coffee Creek is located in the center of this photograph. (Scale 1 cm = 2.3 km)

IV. CONCLUSIONS

A saline seeped area in central Montana was chosen as a study site. Landsat-1 data collected from the site were analyzed by computer programs developed by the Office for Remote Sensing of Earth Resources, The Pennsylvania State University.

The conclusions from this study are as follows.

1. April, May, and August are the best times to detect saline seeps. Specific times within these months would be dependent upon weather, phenology, and growth conditions.

2. Saline seeps can be efficiently and accurately mapped, within resolution capabilities, from merged May and August Landsat-1 data.

3. Seeps are mapped by detecting salt crusts in the spring and indicator plants in the fall. These indicator plants are kochia, inkweed, and foxtail barley.

4. The total hectares of the mapped saline seeps were calculated and tabulated.

5. Saline seeps less than 2 hectares in size or that have linear configurations less than 200 meters in width were not mapped using the Landsat-1 data.

6. Saline seep signatures developed in the Coffee Creek test site were extended to map saline seeps located outside this area.

V. RECOMMENDATIONS

The ability to detect and map saline seeps from Landsat-1 multispectral scanner data is dependent on a number of factors. To develop an efficient program for accurately mapping saline seeps, the following should be considered:

1. Climatic conditions - Maximum salt crustal formation coincides with the time of wet soil conditions. Knowledge of previous climatic and weather conditions is valuable ancillary data.

2. Plant growth rate and maturity - The ability to detect the saline seep indicator plants and to delineate these indicator plants from the agricultural crops is dependent upon phenology. A more thorough understanding of plant growth rates and maturity rates is needed.

3. Crop calendar and management - Knowledge of crop species and location in the area of investigation will aid in the interpretation of scanner data. This should include management practices as well as crop calendar.

4. Harvesting patterns - Investigations should be conducted to determine if saline seep indicator plants can be delineated from harvested wheat.

5. The merging of two or more scenes will increase saline seep mapping capabilities.

6. A color monitoring system, such as the RAMTEK, provides a means for fast display of large classified areas. Mapping capabilities can quickly be determined

from the display and this system should be developed into an operational mode.

7. Further research should be conducted to determine if the saline seep signatures developed in this project can be extended to map saline seeps in other areas of Montana. If signature extension is feasible, then a system should be developed for mapping and inventorying of saline seeps on a statewide basis.

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APPENDIX A

THE PENN STATE ORSER SYSTEM FOR PROCESSING
AND ANALYZING ERTS DATA

THE PENN STATE ORSER SYSTEM FOR PROCESSING AND ANALYZING ERTS DATA

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ABSTRACT

The Office for Remote Sensing of Earth Resources (ORSER) of the Space Science and Engineering Laboratory (SSEL) at The Pennsylvania State University has developed an extensive operational system for processing and analyzing ERTS-1 and similar multispectral data. The ORSER system was developed for use by a wide variety of researchers working in remote sensing. Both photointerpretive techniques and automatic computer processing methods have been developed and used, separately and in a combined approach. A Remote Job Entry (RJE) system permits use of an IBM 370/165 computer from any compatible remote terminal, including equipment tied in by long-distance telephone connections. Detector errors occurring in two channels of every sixth line of ERTS digital data were examined, and a statistical recalibration method was developed. Errors were eliminated after recalibration. Furthermore, after recalibration of data from two ERTS scenes, classification of a forested area yielded excellent results using spectral signatures developed in another area approximately 150 miles away and from an ERTS scene taken 17 days earlier. Thus, transference of signatures in both time and space appears feasible. Specific results obtained by using this system include a study of land use, discrimination between types of forest resources and vegetation, detection of previously unknown geologic faults and correlation of these with known mineral deposits and ground water, mapping of mine spoils in the anthracite region of eastern Pennsylvania, mapping of strip mines and acid mine drainage in Central Pennsylvania, agricultural land use mapping, and detection of gypsy moth infestation.

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THE ORSER SYSTEM

The Office for Remote Sensing of Earth Resources (ORSER) of the Space Science and Engineering Laboratory (SSEL) at The Pennsylvania State University has developed an extensive operational system for processing and analyzing ERTS-1 and similar multispectral data. The ORSER system was developed for use by a wide variety of researchers working in remote sensing. These users represent many disciplines and have a wide range of experience and skill in photointerpretation and computer usage.

Interpretive techniques which are used in the system include computer processing, visual image interpretation, and a hybrid technique which closely integrates photointerpretive techniques with computer analytic procedures.

Computer Processing Facilities

Automatic data processing equipment utilized in the ORSER system is primarily located at The Pennsylvania State University Computation Center. The principal computer is the IBM System 370 Model 165, consisting of a main frame and attached devices for input and on-line storage. Users may have access to the computer in any of three ways: central and remote high speed dispatch points operated by the Computation Center, slow speed Remote Job Entry (RJE) terminals using IBM 2741, Tektronix 4010, or similar remote terminals supported by the user or by the Computation Center, and intermediate speed remote batch terminals, such as the IBM 2780, supported by the user or the Computation Center. The ORSER processing system for MSS data was developed for use with any of these entry points. ORSER investigators use RJE terminals for most developmental work. Bulk output for final runs is directed from an RJE terminal to any of the high speed terminal sites. No program card decks need to be input, as the MSS data processing programs are kept in library files. Files for building control information or for storing output are available to the user. MSS data is input from magnetic tapes which, along with user-owned working tapes, are managed by the Computation Center.

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The Digital Data Processing System

A standard digital tape format was designed within which all known MSS sources can conveniently be placed. More than one file per tape is allowed as well as a continuation of a file to another tape. Within the file, four kinds of records exist: (1) identification records, (2) table of contents records, (3) MSS response records, and (4) history records. Each MSS response record consists of a complete scan line. Each scan line is numbered and scan lines are always in ascending order in a file. A working file will usually contain one or more small parts of the whole data set. The table of contents is particularly useful in such cases in avoiding costly searching for data which are not present in the file.

The system is couched in a multivariate framework. Each observation, identifiable by scan line and element number, consists of a vector with as many components as there are channels. At present, each vector is composed of just MSS response values. It is anticipated, however, that the vectors will be augmented by transformed scanner data, or by additional (nonscanner) data such as topographic information.

Although the system is not in a conversational mode, where the user and the system dynamically interact during processing, the preparation of the control specifications by a user operating from an RJE terminal is conversational. Each program accepts input control specifications, processes the MSS data according to the specifications, and outputs the results. For non-RJE operation, control specifications are made and entered into the system by punched cards. All control specifications on the RJE are identical in format to the corresponding punched cards.

The programs discussed here are all operational and are documented at the user's level. Although many other programs are used, those discussed here illustrate the general approach to the processing of MSS tapes. Detailed descriptions of ORSER programs currently available may be found in ORSER/SSEL Technical Report 10-73.

The digital tape processing system for MSS data described here is regularly run for production and has been extended to meet the needs of various related projects. The system was designed to be easily augmented, typified by the addition of a number of supervised and unsupervised analysis and classification algorithms. The general procedure to be employed for a previously unstudied area or type of target will be presented and illustrated here.

The first step is to select the particular targets and areas of interest, primarily using maps. Consultation of the catalogues of imagery and digital tapes will indicate what data are available and their quality. Tapes corresponding to the selected scenes are chosen and the areas of useful data are specified. Subsets are then produced on separate tapes, using the SUBSET program. These subsets are prepared to gain rapid processing and short turn around time. It is likely that this step has already been done in the process of cataloguing and storing ERTS tapes by ORSER, in which case the appropriate library subset tapes would be selected directly.

A run is then made with the NMAP program to show the overall pattern of the data. This program is written to map element brightness, using all channels or any subset of channels. The norm of each multivariate vector is taken as the measure of brightness. The norm is then converted to a percentage of the maximum possible value. This value is translated to the mapping symbol for the percentage range within which it falls. The process is repeated for every element in every scan line in the data blocks specified by the user. Output from the NMAP program consists, then, of a brightness map.

The UMAP program is run next, to map areas of local spectral uniformity. Each element is compared with its near neighbors using the euclidean distance between spectral signatures as the measure of similarity or dissimilarity. If the largest distance is smaller than a value specified by the user, then the symbol for uniformity is assigned to that element. One or more categories of uniformity can be mapped according to distances specified by the user. All elements with distances from their neighbors greater than those specified are mapped as contrasts. The map output shows the pattern of uniformity and contrasts from which the user can designate coordinates for training areas for the targets of interest and determine high contrast boundaries between uniform areas.

Signatures and associated statistics are next obtained by the use of the STATS program, which computes the multivariate statistics for one or more training areas obtained from UMAP or similar output. The user designates a training area by line and element coordinates and the program computes the statistics for all of the data which fall within the boundaries. The mean and standard deviation vectors are found, and

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the correlation and variance-covariance matrices are computed as well as the eigenvalues and eigenvectors of these matrices. Frequency histograms for selected channels are also computed.

When most of the targets have been identified by training areas, a classification run is made using the classifier or classifiers deemed most appropriate for the mix of targets under consideration. A variety of supervised classification programs are available, including parametric and non-parametric classifiers with either linear or quadratic discriminant functions. Preprocessing before classification is also possible, using programs for normalization, principal components, canonical analysis, etc. The output of these programs is in the form of a character (or digital) map, with each category of classification represented by a unique symbol.

Digital character maps are useful primarily as working maps for the user in the analysis of MSS data. They are inherently distorted in the length-to-width relationship because of the fixed number of lines and characters per inch of high-speed printer output. The LMAP program, yielding output on the CalComp plotter or the RJE terminals with graphic displays, is intended for the production of distortion-free, finished copy, line maps. There are three main advantages to line maps when compared to character maps. (1) orthographic maps to a selected scale can be made, (2) photographic overlays can be prepared for these maps (this is quite important in the comparison of classification results with corresponding imagery), and (3) legible maps for publication purposes can be prepared.

An example of the use of the programs described above is given in Figures 1 through 8. The MSS data used for this analysis came from ERTS-1 scene 1028-15295, scanned on August 20, 1973. This is an area northeast of Clearfield, Pennsylvania, on which U.S. Route 80 and the West Branch of the Susquehanna River cross. The location of the test site is shown in Figure 1, which was taken from two 7 1/2 minute USGS quadrangle maps. The right hand side of this figure is from a map printed in 1959, before Route 80 was constructed, while the left hand side is from a 1971 map. Figures 2 and 3 show map output for LMAP and UMAP, respectively. The strip of low brightness in Figure 2 follows the river, as does the blank (non-uniform) area shown in Figure 3. Basic statistics for the "stripmine" category, obtained by the STATS program are shown in Figure 4. Statistics for the desired categories, as obtained from a series of sample sites, are input to a classification program. Figure 5 shows the output from the DCLASS program which classifies according to a minimum euclidean distance algorithm. In this case, only two general categories are represented by symbols; unclassified elements are left blank. LMAP output using data from the DCLASS program is shown in Figure 6.

It frequently happens that a sample target is not of sufficient size or area to lend itself to categorization using the STATS program. Such targets may be linear features such as streams, or a series of small scattered features which are not large enough to be represented as uniform areas by UMAP. In such cases, these areas are defined for analysis by an unsupervised classifier which develops its own set of

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Figure 1. Test site northeast of Clearfield, Pennsylvania. (Taken from USGS 7 1/2 minute quadrangle maps, "Clearfield" and "Lacontes Mills," both printed in 1971 and 1959, respectively.)

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BLOCK SPECIFICATIONS

 BEGINNING LINE 1030
 ENDING LINE 1059
 BEGINNING ELEMENT 2470
 ENDING ELEMENT 2525
 LINE INCREMENT 1
 ELEMENT INCREMENT 1

	2470	2475	2480	2485	2490	2495	2500	2505	2510	2515	2520	2525
1030	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1031	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1032	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1033	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1034	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1035	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1036	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1037	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1038	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1039	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1040	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1041	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1042	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1043	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1044	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1045	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1046	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1047	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1048	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1049	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1050	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1051	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1052	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
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1055	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1056	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1057	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1058	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											
1059	XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX											

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CLASS : 14.0 CLASS - : 20.0 CLASS X : 100.0

Figure 2 Brightness map (NMAP).

BLOCK SPECIFICATIONS

 BEGINNING LINE 1030
 ENDING LINE 1059
 BEGINNING ELEMENT 2470
 ENDING ELEMENT 2525
 LINE INCREMENT 1
 ELEMENT INCREMENT 1

	2470	2475	2480	2485	2490	2495	2500	2505	2510	2515	2520	2525
1030												
1031												
1032												
1033												
1034												
1035												
1036												
1037												
1038												
1039												
1040												
1041												
1042												
1043												
1044												
1045												
1046												
1047												
1048												
1049												
1050												
1051												
1052												
1053												
1054												
1055												
1056												
1057												
1058												
1059												
	2470	2475	2480	2485	2490	2495	2500	2505	2510	2515	2520	2525

CLASS U . 5.0
 CLASS : 15.0

CLASS - : 8.0
 CLASS * : 100.0

Figure 3. Uniformity map (UMAP).

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```

CHANNELS USED : 1 2 3 4

MEANS AND STANDARD DEVIATIONS FOR GIVEN CHANNELS
-----
29.55    26.86    30.78    13.83
 3.29     4.80     5.21     3.79

VARIANCE-COVARIANCE MATRIX
-----
10.82
14.91    23.09
 0.78     0.23    27.16
-3.27    -5.68    18.00    14.33

CORRELATION MATRIX FOR GIVEN CHANNELS
-----
1.00
0.94     1.00
0.05     0.01     1.00
-0.26    -0.31     0.91     1.00

EIGENVALUES COMPUTED FROM CORRELATION MATRIX.

EIGENVALUES WITH THEIR ASSOCIATED PERCENTAGES:
-----
2.21     1.70     0.06     0.03
55.4     42.4      1.4      0.8

EIGENVECTORS:
-----
0.5227 -0.4645 -0.7059 -0.1129
0.5416 -0.4368  0.6347  0.3362
-0.3800 -0.6257  0.2327 -0.6402
-0.5376 -0.4493 -0.2115  0.6814
DET.=      0.705D-02

SAMPLE CATEGORY : STRIPMINE

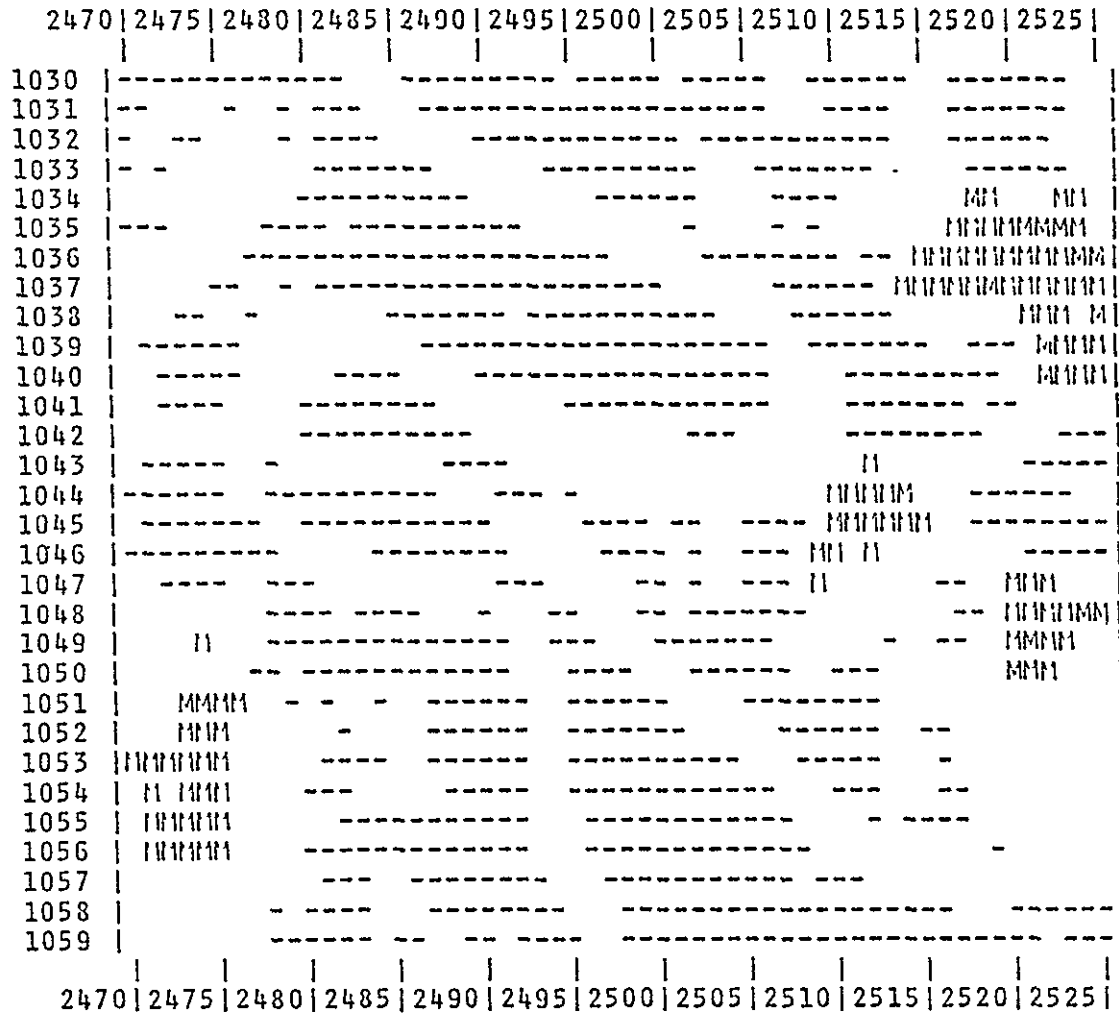
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Figure 4 Statistics of sample areas for a category obtained by STATS.

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BLOCK SPECIFICATIONS

BEGINNING LINE 1030
 ENDING LINE 1059
 BEGINNING ELEMENT 2470
 ENDING ELEMENT 2525
 LINE INCREMENT 1
 ELEMENT INCREMENT 1



SYMBOL M : STRIPMINE

SYMBOL - : VEGETATION

Figure 5. Classification map using signatures obtained by STATS.

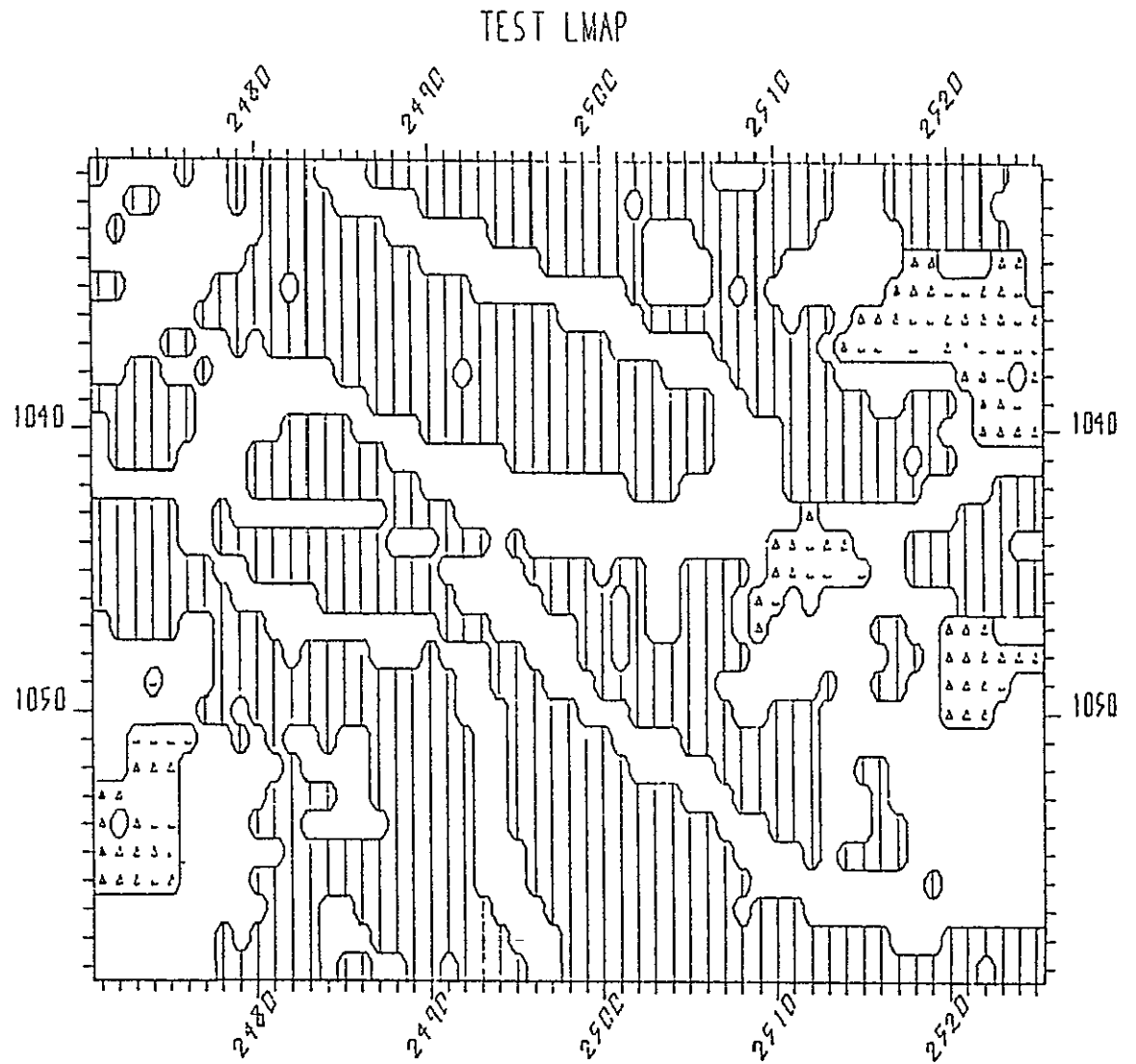


Figure 6 . Preliminary classification map of the Clearfield area (LMAP).

spectral signatures and statistics using a clustering algorithm. The map output of one such program, DCLUS, is shown in Figure 7. A comparison of Figure 7, with the DCLASS output of Figure 5 reveals that DCLUS was able to map some features which could not be mapped by DCLASS with STATS signatures. Map output from DCLASS, using signatures from the DCLUS statistics, is shown in Figure 8 in LMAP form.

The approach employed for change detection or where a temporal dimension is involved is similar to the approach for non-temporal analyses in many respects. The major difference is in the establishment of permanent training areas for supervised analysis and classification and permanent analysis areas for unsupervised analysis and classification. These areas must be selected and specified more carefully and with more refinement than when the temporal dimension is not of interest.

HYBRID ANALYSIS

After separate analyses of ERTS-1 data by photointerpretation alone and by computer processing of MSS digital data without the assistance of photointerpretation, it became apparent that each method had shortcomings which might be overcome if the methods were combined. When applying photointerpretation techniques to ERTS imagery, in only a few cases could a feature be uniquely determined by this method alone. The use of U2, C130 and C54 imagery has been found to improve these interpretation results, but photointerpretive techniques have not been completely satisfactory as a single means of analysis. Computer differentiation of areas from scanner data is far superior to that done by the human eye. Computation of areas from the digital data makes delineation of these areas unnecessary and is far more accurate than planimetric methods at the scale of ERTS MSS imagery. Since the end result of processing ERTS-1 data is a map, the automated processes of thematic mapping by computer is the efficient way to go. However, "ground truth" is the key to correct signatures for this mapping. Underflight data and photointerpretation of underflight photography, as well as of ERTS imagery, are vital links leading to valid signatures for the thematic map. A marriage of these two disciplines, photointerpretation and computer processing, is essential for maximum utilization of ERTS-1 data. Thus ORSER investigators evolved a method of ERTS MSS data analysis referred to as the "hybrid approach" and shown in Figure 9. This method involves intimate interaction of the computer analyst and the photointerpreter, using aircraft photography for comparison with the computer output. A Bausch and Lomb Zoom Transferscope is frequently used for this comparison.

CORRECTION OF BANDING IN MSS DIGITAL DATA

In the ERTS-1 instrument configuration, six banks of the four channel sensors record data for six scan lines simultaneously. MSS digital data have been received in which data for every sixth scan line was found to be inconsistent. The effect was first recognized as banding with a modulo of six in computer output maps. To investigate the

BLOCK SPECIFICATIONS

BEGINNING LINE 1030
 ENDING LINE 1059
 BEGINNING ELEMENT 2470
 ENDING ELEMENT 2525
 LINE INCREMENT 1
 ELEMENT INCREMENT 1

	2470	2475	2480	2485	2490	2495	2500	2505	2510	2515	2520	2525
1030	----	XXXX	----	----	----	----	----	----	XXXXXX	----	----	----
1031	--X++X-	.,XXX-	----	----	XXXX	----	XXXXXX	----	XXXXXX	----	----	----
1032	XXXXXXXX+	..-XX-	----	----	----	----	XXXX	----	XXXX	----	----	----
1033	~XXXXXX	-XX-	----	----	----	----	----	----	----	----	----	----
1034	+XX X+	..-XXX-	----	----	----	----	----	----	----	----	----	----
1035	-----	+++++	----	----	----	----	----	----	----	----	----	----
1036	+	+	----	----	----	----	----	----	----	----	----	----
1037		-XXXXXX	----	----	----	----	----	----	----	----	----	----
1038	..	-XX-*	----	----	XXXXX	----	----	----	----	----	----	----
1039	X----	-X. SSSS+	----	----	XXXXXX	----	----	----	----	----	----	----
1040	XXX----	* S++	----	----	X-XX-	X----	----	----	----	----	----	----
1041	XX----	-X*+	----	----	----	X-X	----	----	----	----	----	----
1042	MM+++++	+	----	----	----	----	----	----	----	----	----	----
1043	-----	+	+++++	+++++	----	----	----	----	----	----	----	----
1044	--XXX-	----	----	----	----	----	----	----	----	----	----	----
1045	+	----	----	----	----	----	----	----	----	----	----	----
1046	----	X----	----	----	----	----	----	----	----	----	----	----
1047	XX----	----	----	----	----	----	----	----	----	----	----	----
1048	+++++	+	----	----	----	----	----	----	----	----	----	----
1049	=====	X-	----	----	----	----	----	----	XXXXXX	XXXXXX	----	----
1050	*	----	----	----	----	----	----	----	XXXX	----	----	----
1051	MM=====	XXXXXX	XXXXXX	----	----	----	----	----	----	----	----	----
1052	MMMMM=====	XXXXXX	XXXXXX	----	----	----	----	----	----	----	----	----
1053	MM=====	XX	XX	----	----	----	----	----	----	----	----	----
1054	MMMMM=	----	----	----	----	----	----	----	----	----	----	----
1055	M=====	XX	----	----	----	----	----	----	----	----	----	----
1056	M=====	+	+	+	+	+	+	+	+	+	+	+
1057	+++++	+	+	+	+	+	+	+	+	+	+	+
1058	+++++	S+	XX	----	----	----	----	----	----	----	----	----
1059	+++++	SSX	----	----	----	----	----	----	----	----	----	----

CHANNELS USED : 1 2 3 4
 INITIAL CRITICAL DISTANCE : 8.5

Figure 7: Signature map by DCLUS.

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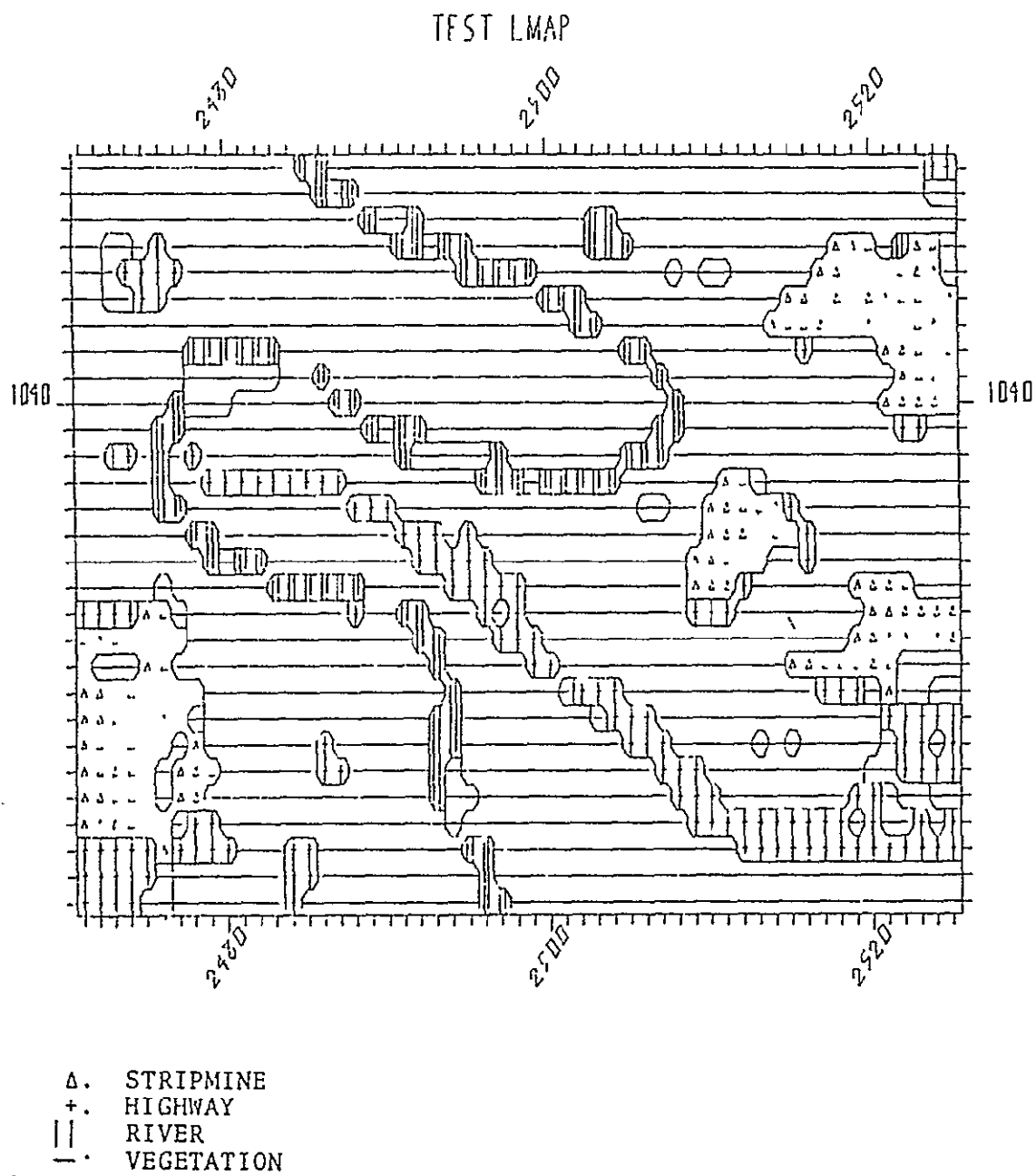


Figure 8 : Classification map of the Clearfield area (LMAP).

Explanation of the steps shown in Figure 9.

PRELIMINARY PROCEDURES

- A. ¹ Determine scan line and element limits
- B. This becomes the working tape.
- C. Identify clouds
- D. Review scene for definable boundaries

FIRST LEVEL MAPPING

- A. Collaboration of the photointerpreter and computer mapper. Select easiest targets first. Choose spectrally homogeneous items with positive geographic locations. Select replications in widely separated areas
- B. Identify some targets (training areas) on NMAP or UMAP
- C. Check for uniformity on UMAP. Attempt to find a large number of like elements. Loop A, B, and C until a sufficient number of training areas are identified
- D. Review statistical characteristics of defined targets
- E. Make first run on classification map
- F. This is a verification step. Project U2 image onto computer map. Identify satisfactory classifications. If some areas lack definition, redefine training areas.

SECOND LEVEL MAPPING

- A. Attempt to identify items outside training areas.
- B. Define items not subject to definition by training areas. These might be linear features or stream channels. Add these to the list of signatures and continue.
- C. This a recycle, with smaller training areas and more weight placed on cluster analysis

THIRD LEVEL MAPPING

- A. Review the classification categories originally defined as desirable. If present map output is unnecessarily refined, combine some groups
- B. Some categories will require broadened spectral parameters. A series of successive approximations will be required to define these units. The resulting training areas will be less spectrally homogeneous
- C. Requires collaboration of the photointerpreter and the computer mapper
- D. Establish limiting goal.

¹The letters correspond directly to those shown in the diagram

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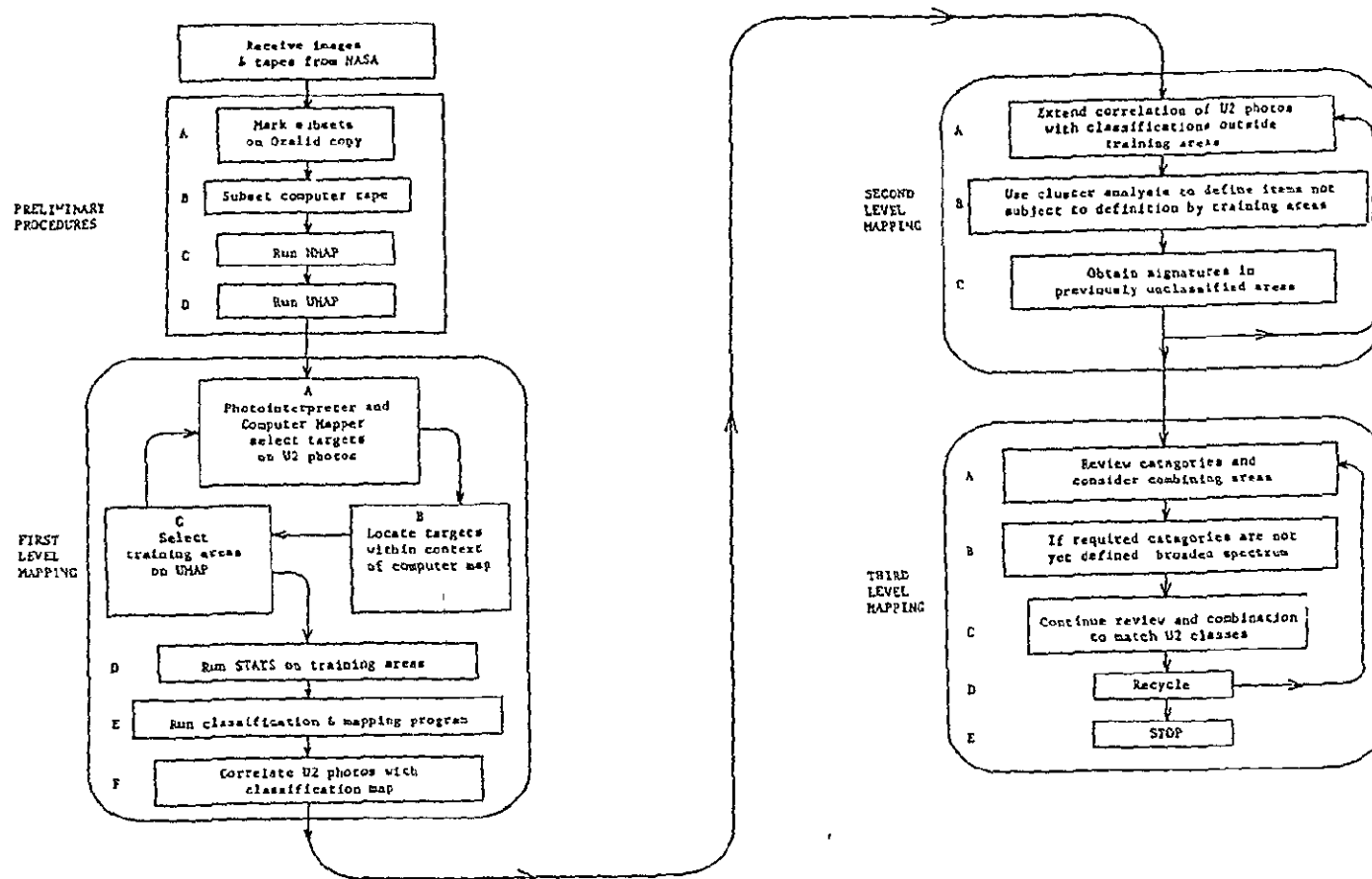


Figure 9 Flow diagram for the hybrid approach to ERTS data processing

problem, the NMAP program was extended to compute the mean and variance for each channel for each line modulo six. In some cases it was determined that the mean value of every sixth line was less than one-tenth the value for each of the other five lines for the third MSS channel. (The other three channels were consistent for the first five scan lines.) Similarly, the standard deviation of the sixth line in the fourth MSS channel was found to be about six times larger than corresponding values for the other five lines.

It was apparent that the data could be recalibrated, at least in an approximate way, by use of the MSS data alone. Output from the NMAP program indicates which sensors in which of the six banks of sensors are involved. The SUBSET program has been extended to allow input of recalibration parameters for the offending sensor data. The following correction is then applied:

$$\hat{X}_{ijk} = [(X_{ijk} - \bar{X}_{kl})/s_{kl}] * s'_{kl} + \bar{X}'_{kl}$$

where

$\hat{X}_{ijk}$ is the recalibrated value for scan line i, element j, and channel k;

X_{ijk} is the corresponding original value,

$\bar{X}_{kl}$ is the computed mean for channel k and for line $l = \text{modulo}(j, 6) + 1$ taken from NMAP output,

s_{kl} is the corresponding standard deviation,

s'_{kl} is the recalibration standard deviation computed as the average of unaffected standard deviations for channel k based on NMAP output, and

$\bar{X}'_{kl}$ is the corresponding recalibration mean.

This correction has eliminated the banding problem in all data to which it has been applied.

RESULTS

The applications objectives of the ORSER interdisciplinary investigation are grouped into three major categories. (1) geology and hydrology; (2) inventory of natural resources and land use, and (3) environmental quality.

Applications

Specific results obtained to date include a study of land use, discrimination between types of forest resources and vegetation, detection of previously unknown geologic faults and correlation of these with known

mineral deposits and ground water, mapping of mine spoils in the anthracite region of eastern Pennsylvania, mapping of strip mines and detection of acid mine drainage effects in Central Pennsylvania, agricultural land use mapping, and detection of gypsy moth infestation.

Temporal and Spatial Transference of ERTS Spectral Signatures

Spectral signatures were developed for various vegetative and water targets in a forested area near the East Branch Reservoir in north-central Pennsylvania, using data from ERTS scene 1028-15295 for August 20, 1972. These signatures were then used to classify targets in the Stone Valley Experimental Forest for scene 1045-15243 of September 6, 1972. These signatures were initially used without success. The data for the two scenes were then recalibrated to match means and variances by channel and modulo line number in accordance with the recalibration algorithm given above. After this recalibration, excellent classification of the Stone Valley area was achieved using data from the East Branch area. Since the signatures used for classification were developed from ERTS data collected 17 days earlier and in an area approximately 150 miles away from Stone Valley, it appears that transference of spectral signatures in both time and space is feasible.

COST ANALYSIS

Two major components of the cost for analyzing and interpreting ERTS-1 digital data are computing cost and personnel cost. Computing cost can be partitioned into the cost for spectral signature identification and the cost for processing bulk data after signatures have been identified. The major personnel cost is associated with the development of signatures, since remote sensing analysts and interpreters are required for this phase. In the processing of bulk data, much less personnel time is required, although analysts and interpreters remain closely involved in evaluating the products.

In the Susquehanna River Basin test site in Pennsylvania, two characteristics dominate the analysis and interpretation of ERTS-1 data. These are the diversity of targets and the areal smallness of target units. Compared with other areas where these characteristics are less pronounced, signature identification presents a greater challenge and is therefore likely to be more costly. In addition, the cost for signature identification is contingent upon the nature of the particular problem to be solved and therefore it is difficult to categorically specify this cost.

In the computation cost evaluations provided here, the computer run costs are based on the standard rates charged at the Computation Center of The Pennsylvania State University. The ORSER MSS computer analysis methods emphasize the minimization of computation costs by being designed for signature identification based on short computer runs on small subsets of ERTS-1 data.

Data for personnel and computation cost were obtained for a typical ERTS scene analysis. For the identification of 22 signatures judged necessary

to meet the analysis objectives, the personnel cost was \$400 and the computation cost was \$600, a total of \$1000. Using the 22 signatures, mapping of a full ERTS-1 scene cost \$560, based on a cost of \$0.043 per square mile. Considering signature identification cost plus full-scene processing cost, the cost per square mile was \$0.12. For subsequent scenes of the same area, signature identification cost would be expected to be substantially less because, in the first time through, a great deal of personnel time and computer cost are spent in familiarization and learning for the specific area and targets. Much of this work does not have to be repeated in subsequent analyses of the same area.

Data have been accumulated for the computation costs of running different programs. For subsetting a complete ERTS-1 digital tape, the cost has averaged \$0.032/square mile. The cost of running mapping and classification programs has been found to be dependent on the number of signatures as well as the area to be mapped. The dollar cost per square mile (C) as a function of the number of signatures (S) has been found to adhere to the following formula.

$$C = S (2.56) 10^{-3}$$

For 15, 30, and 60 signatures, this cost is \$0.038, \$0.075 and \$0.154, respectively.

The computer time required for running mapping and classification programs is also dependent on the number of signatures and the area to be mapped. Typically, one complete ERTS scene can be classified using eight categories in approximately one hour.

The above calculations of analysis and processing costs have not taken into account the cost of developing the digital computer processing system. The system was developed so that it could be easily used for processing ERTS-1 as well as any other satellite or airborne platform MSS digital data. The system development has not been financially supported by the ERTS-1 project, although it has received partial NASA support through a sustaining University grant. Extension and modification of the system has been partially supported in the ERTS-1 project.

APPENDIX B
INTERACTION WITH POTENTIAL USERS
AND INVESTIGATORS

Saline seep investigators and potential users were contacted during this study. Many of these people were a valuable asset to the study. Following are the names, addresses, and brief descriptions of the people and organizations that interacted with personnel on the Penn State saline seep project. Some of the correspondence from these people are also included in this Appendix.

Jack W. Rodgers
Montana State Soil Scientist
P. O. Box 970
Bozeman, Montana 59715

Selected study site for the project and supplied 1:24,000 and 1:40,000 aerial photographs of the site.

Clair Clark
Soil Conservation Service
Lewistown, Montana 59457

Organized a 2-day field-trip to the study site and other saline seeped areas. Provided detailed information on all aspects of the saline seep problem in Montana and study site. Evaluated and field checked final mapping results.

Paul L. Brown
Agricultural Research Service
P. O. Box 45-1307
Fort Benton, Montana 59442

Gave a tour of the Highwood Bench in Chauteau County, Montana which is a saline seep area being studied by the Chauteau County Alkali Control Association and also the Old West Commission.

Old West Commission

Comprised of researchers from Montana, North Dakota, and South Dakota. A copy of the proposal to study the saline seep problem with remote sensing techniques is given in this Appendix.

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Donald G. Moore
Remote Sensing Institute
South Dakota State University
Brookings, South Dakota 57006

Member of the Old West Commission. Sent a map showing the location of flight lines for data collection over saline seep areas in Chauteau County, which was flown for the Old West Commission. A copy of the Penn State Saline seep final report was sent to Mr. Moore.

Gerald A. Nielsen
Plant and Soil Science Department
Montana State University
Bozeman, Montana 59715

Member of the Old West Commission. Several telephone conversations concerning the Penn State saline seep project and the Old West Commission saline seep project. There was an exchange of research proposals and research objectives and the possibility of mutual study sites.

Robert S. Duncan
Administrator, Staff Services Administrator
Department of State Lands
Helena, Montana 59601

Requested information on the Penn State saline seep project. A copy of the final report was sent to Mr. Duncan.

Roger Veseth
Saline-Alkali Program
Department of State Lands
Helena, Montana 59601

Requested information on the Penn State saline seep project. A copy of the final report was sent to Mr. Veseth.

Leland Cade
Editor for Montana Farmer-Stockman
Professional Building
Great Falls, Montana 59401

Interviewed Gary Petersen and George May and wrote an article in the Montana Farmer-Stockman concerning the application of remote sensing techniques to the saline seep problem.



DEPARTMENT OF STATE LANDS

STATE CAPITOL

HELENA 59601

(406) 449-2074

September 15, 1975

Dr. Gary W. Peterson, Codirector
Office of Remote Sensing & Earth Resources
219 Electrical Engineering West
Pennsylvania State University
University Park, PA 16800

Dear Dr. Peterson:

The Department of State Lands is responsible for coordination of saline seep related research and control projects in Montana.

Recently, we were informed that you and George May are currently attempting to utilize ERTS IR remote sensing to delineate and map saline seeps in Montana, and that you have been in contact with Dr. Paul Brown, ARS, Fort Benton.

It would be highly appreciated if you could supply us with any additional information concerning this ERTS project and what may be some of your preliminary conclusions as to the usefulness of ERTS for saline seep detection and monitoring.

Allow me to thank you in advance for your cooperation. Wishing you the best of luck in your efforts.

Sincerely,

Roger Veseth
Saline-Alkali Program

RV/aj

RESOURCE

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PRESENT

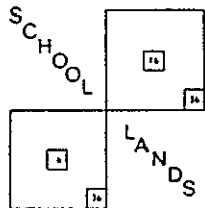
OPPORTUNITY

FOR THE
FUTURE

B-4

OFFICE FOR
REMOTE SENSING OF EARTH RESOURCES
219 ELECTRICAL ENGINEERING WEST

SEP 17 1975





REMOTE SENSING INSTITUTE



SOUTH DAKOTA STATE UNIVERSITY

605/688-4184

BROOKINGS, SOUTH DAKOTA 57006

June 23, 1975

Dr. George May
Office for Remote Sensing of Earth Resources
Pennsylvania State University
219 Electrical Engineering, West
University Park, Pennsylvania 16902

Dear Dr. May:

We are enclosing a copy of a map which shows the location of the flight lines for data collection over saline seep areas in Chouteau County, Montana. The weather has not been suitable so far to enable us to complete the data collection flights. Frequent weather checks are being made and we will proceed as soon as some clear skies are available.

Any information which you have developed concerning saline seeps would be greatly appreciated. We would also like to be placed on your mailing list for information which may become available to you in the future. In return, we will be pleased to cooperate with you in any way we can to exchange information on our efforts.

Sincerely,

A handwritten signature in cursive script that reads 'Donald G. Moore'.

DONALD G. MOORE
Soil Scientist

DGM/ss

Enclosure

Montana State University

College of Agriculture

Agricultural Experiment Station
Bozeman, Montana 59715

Tel 406-994-4601

Plant and Soil Science Department

February 20, 1975

Mr. George May
Office For Remote Sensing
of Earth Resources
219 Electrical Engineering West
Pennsylvania State University
University Park, Penn. 16802

Dear George:

Enclosed is a copy of the research proposal that we discussed recently by phone. This project has been funded by the Old West Commission and work has begun in South Dakota, North Dakota and Montana.

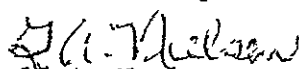
The first flight will be made between the first and tenth of May, the second no later than mid September, and the third has yet to be scheduled. If we can work out a cooperative effort it would seem likely that adjustments could be made so that the flights would coincide with the ERTS overpass.

In Montana there will be high elevation and low elevation flights with flight widths approximately 10 miles and 1/2 mile respectively. The locations are as follows: Chouteau County, on the boundary line between R17E and R8E for the entire length of T22N. In Stillwater County the flight is on the line between T4N and T3N and includes half of R20E and half of R21E.

I suggest that you contact Donald G. Moore, Research Soil Scientist, Remote Sensing Institute, South Dakota State University, Brookings, South Dakota 57006. His phone number is area code (605) 688-4184.

If I can do anything to help bring about a coordinated effort with regard to the identification of saline seeps, please call on me again.

Sincerely,


Gerald A. Nielsen
Professor of Soil Science

GAN:ddg

Encl. - 1

CC: K. C. Feltner, Dept. Head

Jim Krall, Saline Seep Program Coordinator



DEPARTMENT OF STATE LANDS

STATE CAPITOL

HELENA 59601

(406) 449-2074

STATE BOARD OF
LAND COMMISSIONERSTHOMAS L. JUDGE
GOVERNORDOLORES COLBURG
DEPT. OF PUBLIC INSTRUCTIONFRANK MURRAY
SECRETARY OF STATEROBERT L. WOODAHL
ATTORNEY GENERALE. V. SONNY OMHOLT
AUDITOR

March 7, 1974

Mr. Gary Peterson
Penn. State University
University Park, Pennsylvania 16802

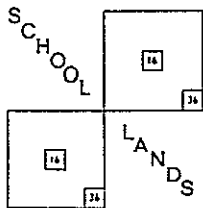
Dear Mr. Peterson:

This Department may soon have the responsibility for implementing saline seep programs in Montana. I understand that you or George May have done some work on remote sensing detection of saline areas. Information on your work would be appreciated.

Sincerely,

ROBERT S. DUNCAN, Administrator
Staff Services DivisionTED SCHWINDEN
COMMISSIONER

RSD:pm

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FUTURE

B-7

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

P. O. Box 970, Bozeman, Montana 59715

SUBJECT SOILS - Fergus County

DATE July 27, 1973

AIR MAIL

TO Dr. Harold L. Mathews
NASA
Goddard Space Flight Center-Code-650.3
Greenbelt, MD. 20771

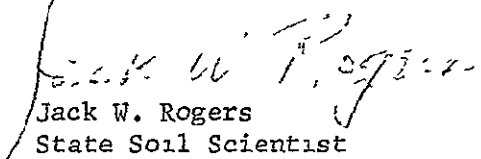
Dear Dr. Mathews:

Enclosed are two sets of aerial photography of the area around the small community of Coffee Creek in Fergus County, Montana.

The flight line is east-west and the scale is 1:40,000.

Also enclosed is a Montana State Highway map and a map of Fergus County. Will send you another county highway map next week.

Sincerely,

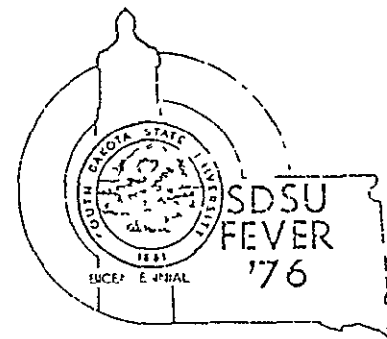

Jack W. Rogers
State Soil Scientist

cc: Linford



12/1/74

SOUTH DAKOTA STATE UNIVERSITY
BROOKINGS, SOUTH DAKOTA 57006



"Teter"—From Experience—
Vision in Education and Research

WATER RESOURCES RESEARCH INSTITUTE

October 18, 1974

TO. Billings Saline Seep Tri-State Workshop Participants

FROM Maurice L. Horton /msh/

SUBJECT: Saline Seep Project

RECEIVED

OCT 21 1974

WATER & SOIL
SCIENCE DEPT

The attached saline seep research proposal has been prepared for anticipated submission to the Office of Water Research and Technology as a matching fund project

The first draft was prepared by Maurice Horton and should be considered a work copy. Please examine this proposal and make comments to John Wiersma of South Dakota or to E. B. Norum of North Dakota or to Ted Williams of Montana.

Since the proposal is due in the OWRT office November 1, 1974, all changes must be made quickly. Details regarding contract and administration of funding can be worked out later through the OWRT directors.

I will be calling the above named contact men on October 23 for proposal changes.

I realize that the proposal will need considerable revision before it is ready for submission. Please make your comments and desires known.

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B-9

PROJECT OUTLINE

TITLE Water Conservation and Saline Seeps

PROJECT DURATION.

Beginning August, 1975 and ending January, 1978

PROJECT OBJECTIVES:

The purpose of this study is to develop and test techniques for detection of potential saline seeps before they become problem areas. Saline seeps are recently developed wet salty areas in which the soil surface is continuously or intermittently wet. White salt crusts are often present and crop production on the seep area is reduced or eliminated.

Specific Objectives

1. To determine if the appearance of new seep areas can be predicted from the reflective or thermal characteristics of the land surface.
2. To test the accuracy of saline seep detection using surface characteristics by comparison with a standard ground survey method.
3. To determine the feasibility of using the surface characteristics method to survey the increase or decrease in seep affected soils over a broad region. *is this defined*

RELEVANCE OF RESEARCH:

It seems incredible that a system of dryland farming developed for the Northern Great Plains could conserve sufficient water to create a new problem, saline seeps.

The problem stems from the geology of the region coupled with excess water moving through the soil profile. The soils of much of the Northern Great Plains are underlain by salt laden shales which serve as a barrier to downward movement of water. Excess water accumulates during fallow periods,

during periods of high rainfall, or during periods of snowmelt. Over a period of years the excess water moves through the soil profile and collects on top of the salty shale barrier. The salt enriched water gradually moves down-slope where it accumulates in low areas (discharge areas) and eventually breaks out at the ground surface. The water evaporates at the soil surface leaving behind the soluble salts. Eventually the discharge area becomes too saline for plant growth.

In addition to the land removed from production in the active seep areas, the surrounding land becomes difficult to manage. Active seep areas cannot be crossed with farm machinery; therefore, farm operations require irregular patterns which cause considerable inconvenience to the operator.

In addition to the inconvenience of farming around seep areas, the most effective crops for planting on the recharge or discharge areas are not always crops that fit the farming operation.

Geological conditions favoring saline seep formation are present over vast areas of Montana, North Dakota, South Dakota, and Canada. Miller and Bond (1973) estimate that a total of 228,000 square miles of the Northern Great Plains are potential areas for saline seep development. Figure 1 illustrates the region of concern.

Miller and Bond (1973) estimate that the Missouri Basin is storing water equivalent to approximately an inch of precipitation per year. The groundwater buildup associated with the alternate crop-fallow system appears to be the most reasonable explanation for the runoff deficit in the Missouri Basin.

With more than 30 years of water accumulation, recent growth of saline seeps has been extensive and rapid. For example, Cade (1973) presented data from the Soil Conservation Service showing a growth in saline seep affected area in Montana from 55,700 acres in 1969 to 152,500 acres in 1973. A recent

(September 18-19, 1974) Saline Seep Conference held in Billings, Montana, indicates a parallel growth of the problem in North Dakota and South Dakota.

Several recent workshops or conferences have singled out the saline seep problem as a high priority research area. The OWRT Evapotranspiration Workshop held in Manhattan, Kansas, on June 4-5, 1974, recognized saline seeps as a research problem of highest priority. The Missouri Basin Commission cited saline seeps as a Basin concern at the Commission's 1974 Summer Meeting. The special Saline Seep Conference held in Billings, Montana, on September 18-19, 1974, explored the extent of the seep problem, current investigations and research needs relative to saline seeps. One area of research that was recognized was the need for techniques that would permit detection of potential seep sites before they become problem areas.

The research proposed here attempts to fill an important gap in the knowledge about saline seeps. Early detection of potential seeps would make it possible to identify and initiate treatment of the recharge and discharge areas to prevent formation of an active seep.

RESEARCH PROCEDURES:

The proposed research procedures utilize recently developed ground survey techniques for saline seep study together with an experimental approach based on the reflective and thermal properties of surfaces. The presence of a high water table and the growth of indicator plants should provide detectable photographic or thermal characteristics that will indicate potential seep sites.

The Specific Procedures are:

1. Selected ground sites in Montana, North Dakota, and South Dakota

will be flown by aircraft to collect photographic and thermal imagery of potential seep areas.) The Remote Sensing Institute in Brookings, South Dakota, will be responsible for the aircraft data collection, duplication of film for users, providing prints of the study area and for developing interpretative procedures.

As soon as imagery and analysis procedures are developed, a training conference will be held to prepare the project participants for analysis of the data from each ground site.)

Potential seep sites located on the imagery will be verified by ground survey. Each state will be responsible for conducting

its ground survey. # of acres? ; scale of photos? the working scale

2. The accuracy with which saline seeps can be detected from sur-

face characteristics will be determined by comparison with ground

observations using the 4-probe method as described by Rhodes and

Halvorson (1974). Montana and North Dakota have experience in

4-probe field studies. Each state will be responsible for its

respective 4-probe surveys. Suitable common statistical techniques

will be used for comparing imagery analyses with 4-probe results.

B-13

Does 4-probe identify potential seeps?
If so, with how much lead time? Can

- time
3. Changes in the imagery from one observation to the next will be used to determine if the increase or decrease in seep affected ^{over what time period?} soils can be determined by survey of broad regions. Simple change detection procedures using diazo prints or machine color coding should give a measure of the rate of increase or decrease in seep area. ✓ ok

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- An additional procedure that relates to objectives 1 and 3 is the use of specialized imagery enhancement techniques. The Remote Sensing Institute has Signal Analysis and Dissemination Equipment (SADE) and color enhancement equipment (I²S). Selected imagery of ground sites will be analyzed using standard machine procedures to determine if image enhancement can separate out seep areas from non-seep areas. The advantage of the image enhancement technique is the rapidity with which seep areas could be surveyed. ✓ ok
5. A significant feature of the project will be the coordination of procedures and data interpretation techniques. Periodic conferences are planned to assure that the research workers in each state are using appropriate methods. The greatest benefit of the conferences may be the information dissemination that will occur. Inclusion of extension specialists at the conferences will assure technology transfer to the farmer with the problem. The real payoff for the project will be if active seeps can be prevented or remitted by timely treatment of recharge and discharge areas. ✓

B-14

short term or periodic change in climate may be a major contributor to the saline seep problem. Is this recognized in the present proposal? What is duration of this project? Will climatic data be analyzed enough to indicate whether seeps should theoretically be prevented or remitted by timely treatment of recharge and discharge areas?

RELATED RESEARCH.

Are there geomorphological or pedological indicators of potential saline-susp discharge + recharge areas? Since land form + slope relationships are factors in the seep problem I assume that they may have capabilities for stereoscopic investigations or some other means of measuring slopes, relief, drainage, etc.

PUBLICATION PLAN:

In addition to the OWRT completion report, the research results will be published in appropriate state bulletins and national or international journals. It is anticipated that the Journal of Soil and Water Conservation or the Soil Science Society Proceedings would be likely publication avenues. Popularized state publications on research results will also be included.

INFORMATION DISSEMINATION PLAN:

Potential users of the research results include extension workers, county agents, farmers, soil conservation personnel and other workers in soil and water.

The initial dissemination of results will be through planned joint state conferences where soil and water extension workers are expected to participate. In addition, research progress reports and, perhaps, oral presentations will be given to interested groups.

PRINCIPAL INVESTIGATORS.

Montana:

North Dakota:

South Dakota. Maurice L. Horton
Donald G. Moore

(Biographical sketches to be added)

Project Officer:

John L. Wiersma

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TRAINING ACCOMPLISHMENTS.

One of the training objectives will be to develop saline seep indicators for use by extension and field personnel. The indicators may include surface geology, reflectance, thermal, and plant components.

Students or research assistants employed for field or laboratory work will receive training in use of 4-probe equipment and in photo interpretation.

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PROPOSED BUDGET
(Not in correct OWRT Form)

Total for Project

<u>ITFM</u>		<u>MT</u>	<u>ND</u>	<u>SD</u>
1. Aircraft Data Collection				
Film Supplies				
Film Processing				
Image Enhancement				
Total	\$38,000			
for 9 flights				
(3 per state)				
		This is budgeted to the Remote Sensing Institute and is considered to provide equal support for each state.		
2. Personnel				
Staff Support	\$18,000	6,000	6,000	6,000
Student Labor	<u>3,000</u>	1,000	1,000	1,000
Total	\$21,000 + equal matching			
3. Travel				
Conferences and Field	<u>\$12,000</u>	4,000	4,000	4,000
Total	\$12,000 + equal matching			
4. Equipment				
Light Tables(3)	\$ 900	300	300	300
4-Probe(3)	1,500	500	500	500
Misc.	<u>600</u>	200	200	200
Total	\$ 3,000 + equal matching			
5. Publication and Information Dissemination				
Total	<u>\$ 3,000</u>	1,000	1,000	1,000
	\$ 3,000 + equal matching			
6. OWRT Total	\$77,000			
Matching Total	<u>77,000</u>			
TOTAL	<u>\$154,000</u>			

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PREPARE FOR SALINE SEEP CONFERENCE

I. Project Goals & Objectives.

- Pages 6-9 of OWRC Proposal.
- Discuss objectives & tasks.
- RSI flights #1 & #2 are research (May 75
Sept. 75
RSI flight #3 may be survey oriented. → Map.

II. Ground Truth

- Ground Truth Specialist -- MT & ND
- Data Requirements -- Form
 - Land Use Along Flight Line -- overlay on base map.
 - Soils & Geologic Materials Along Flight Line -- overlay on base map.
 - Location of Seeps by Class Along Flight Line -- overlay on base map.
 - Ground Photographs Along Flight Line -- overlay on base map.
 - Four-Probe Data.
 - Size of Seep Affected Areas Along Flight Line

III. Flight Plan Maps -- Actual location of flights

IV. Plan of Work

- Conference #1 -- Jan. 29-30, 1975
- Pre-flight & Field Data -- Feb. - May, 1975
- Flight #1 -- May, 1975 — May 15-25 for MT.
- Ground Truth & Data Products Processing -- June - July, 1975
- Photo Interpretations Training - Conference #2 -- August, 1975
- Ground Truth and Pre-Flight Planning -- August, 1975
- Flight #2 -- September, 1975 → set at latest
- Photo-Interpretation & Ground Survey -- Sept.-Oct., 1975
- Image Analysis -- Nov. - Dec., 1975
- Data Analysis -- Jan. - March, 1976
- Data Processing, Interpretations, Enhancement, Etc. -- Apr. - Sept., 1976
- Conference #3
- Flight #3
- Data Summaries, Preparation of Final Report for OWRC -- Oct. - Dec., 1976
- Completion of OWRT Work, Preparation of Manuscripts -- Jan. - Sept., 1977
- Final Report OWRT & Publications -- Oct. - Dec., 1977

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